



available from other parts of the year from this region. The present study provides data on the number of Red Knots, and their biometry, moult, food and body mass, and provides a better understanding of the role of coastal areas of northern Brazil in the long-distance migrations of this species.

## Study area

Observations were made at two study areas, Curupu Island and Panaquatira Beach, both in the Gulf of Maranhão (02° 28' S, 44° 00' W), in São José Bay at the eastern extreme of São Luís Island (Fig. 1). The whole region is within a wide estuarine area created by the mixture of the salty waters of the Atlantic Ocean with the fresh waters from the Itapecuru, Mearim and Pindaré rivers. Maximum tidal amplitude in this coastal sector can reach 8 m (Mabesoone & Coutinho 1970).

The landscape of the north-central coast of Brazil differs completely from the northernmost portions of South America because it is deeply indented, presenting a series of sand banks separating shallow bays (Morrison *et al.* 1987, Morrison & Ross 1989). A progressive transition from coarse sediments along the outer coastlines to fine sediments in the inner bays produces a wide variety of habitats, reflected in the impressive numbers of shorebirds using the coast (Morrison & Ross 1989, Rodrigues & Roth 1990, Rodrigues 1993). In May 1993, this area was recognized as a "hemispheric site" by the Western Hemisphere Shorebird Reserve Network.

## Methods

Intermittent expeditions to the study area have been carried out since 1992, providing some qualitative data used here. Expeditions to Curupu Island, which corresponds to Morrison & Ross's (1989) sector 59, were carried out between January and March 1997. Panaquatira Beach, approximately 4 km south of Curupu, was visited monthly between July 1996 and May 1997. Counts were carried out on Curupu Island and Panaquatira Beach at high tide and during the ebb tide. All observations were carried out using 10 x 50 binoculars and a 15-60 x telescope. Special efforts were made to scan migratory flocks of Red Knots to look for colour-marked birds ringed elsewhere.

Some birds were mist-netted at night at Panaquatira Beach. Each bird received a CEMAVE (Centro de Pesquisas para a Conservação das Aves Silvestres-IBAMA, Brazil) metal ring and some received colour rings. Wing length (maximum chord) (Evans 1964) was measured to the nearest mm. Bill was measured to the nearest 0.1 mm from the tip of the upper mandible to the feather-margin. Body mass was obtained using 300g Pesola balances, and the birds were also examined for moult (see Prater *et al.* 1977, Hayman *et al.* 1986). Values presented are means  $\pm$  SD. We used one way ANOVA to compare mean body mass between months.

The densities of the benthic fauna in Red Knot feeding areas were analysed via sediment samples collected in December 1996 (Panaquatira Beach) and in February 1997 (Curupu Bay). The samples were collected using a PVC cylinder 110 cm long and 10 cm in diameter (Rebelo, 1986). Fifteen cores, representing a total area of

0.15 m<sup>2</sup>, were taken at each study site. The benthic organisms were sorted in the field using sieves with overlapping meshes of 1.0 mm and 0.5 mm. The collected material were anaesthetised with MgCl<sub>2</sub>, fixed in 10% formaldehyde, and subsequently conserved in 70% alcohol for identification. The stomach contents of a Red Knot which died during a ringing expedition in April 1996 were also analysed.

The length (to the nearest 0.1 mm) of bivalve molluscs was measured from the widest point of the anterior region to the widest point of the posterior region (Rios 1975) using calipers.

## Results

Bill lengths of Red Knots from mixed sex samples caught in Panaquatira Beach ( $\bar{x} = 35.6 \pm 2.2$ ,  $n = 60$ , Table 1), do not differ from populations passing through or wintering in other parts of South America (Surinam  $\bar{x} = 35.6 \pm 1.68$ ,  $n = 35$ ; southern Brazil  $\bar{x} = 35.9 \pm 2.15$ ,  $n = 20$  and Argentina  $\bar{x} = 36.2 \pm 1.92$ ,  $n = 273$  – see Morrison & Harrington 1992: table 2), although there appear to be two main groups wintering in South America.

Red Knots use this stretch of the north-central coast of Brazil throughout the year and winter in concentrations of up to 1,000 individuals (Fig. 2). One bird banded at Panaquatira Beach as a juvenile in April 1996 was recaptured at the same site in early May 1997. During autumn migration, numbers varied, presumably due to the movements of recently-arrived individuals (Fig. 2). During spring migration, numbers decreased from February to May in the Gulf of Maranhão (Fig. 2), suggesting that some birds move to more northerly areas, probably to Maiaú Island in the west coast of Maranhão (*c.* 170 km distant – where Wilson *et al.* (1998) recorded 355 birds in early May), to accumulate fat reserves before the next stage of the flight. However, some individuals were observed at the end of April and early May in breeding plumage in the Gulf of Maranhão.

Two roosting areas used by Red Knots during high tide were identified (Fig. 1). The first, on Curupu Island, had the greatest observed wintering concentrations of

TABLE 1.  
Measurements (mm) and body mass (g) of Red Knots caught on Panaquatira Beach, Maranhão, Brazil

Date	Wing $\bar{x} \pm SD$	Bill $\bar{x} \pm SD$	Tarsus $\bar{x} \pm SD$	Mass $\bar{x} \pm SD$
16 December 1993 ( $n = 5$ )	169.8 $\pm$ 5.4	36.0 $\pm$ 1.1	33.0 $\pm$ 2.1	109.2 $\pm$ 7.3
08 September 1996 ( $n = 4$ )	168.2 $\pm$ 6.6	36.6 $\pm$ 1.5	33.3 $\pm$ 0.8	106.5 $\pm$ 11.2
14 April 1996 ( $n = 9$ )	168.8 $\pm$ 4.7	33.4 $\pm$ 3.0	32.1 $\pm$ 1.7	120.1 $\pm$ 14.8
27 April 1996 ( $n = 4$ )	168.5 $\pm$ 3.1	35.8 $\pm$ 0.9	32.7 $\pm$ 1.7	136.7 $\pm$ 13.3
29 March 1997 ( $n = 15$ )	163.5 $\pm$ 5.8	36.1 $\pm$ 2.3	33.7 $\pm$ 2.6	118.9 $\pm$ 9.0
12 April 1997 ( $n = 5$ )	166.6 $\pm$ 5.1	36.4 $\pm$ 1.3	33.0 $\pm$ 1.2	113.0 $\pm$ 3.9
05 May 1997 ( $n = 18$ )	165.0 $\pm$ 4.3	36.4 $\pm$ 1.4	33.0 $\pm$ 1.1	142.1 $\pm$ 8.7

individuals (1,200); Knots were generally associated with Short-billed Dowitcher *Limnodromus griseus*, Black-bellied Plover *Pluvialis squatarola*, Ruddy Turnstone *Arenaria interpres*, Sanderling *Calidris alba*, Semipalmated Sandpiper *C. pusilla* and Semipalmated Plover *Charadrius semipalmatus*. The greatest concentration of individuals observed at the second area, on Panaquatira Beach, was 800. If these two records represent separate waves, the total number of Red Knots wintering in this sector of the coast may reach 2,000.

### Moult schedule

Five adult Red Knots caught in October 1995 and September 1996 had wing moult (primaries 4, 5, 6 and 7). In December 1993, two adults had completed primary moult and three were moulting primary 10, suggesting that this was towards the end of the moulting process. Two individuals were moulting tail feather number 1 in September 1996, whereas none were in moult in December 1993. No birds captured in April 1996 ( $n = 13$ ), March, April and May 1997 ( $n = 38$ ) were moulting remiges or rectrices.

Body moult into winter plumage was observed in October 1995 and September 1996, but not in December 1993. In April 1996 and 1997, and May 1997, body moult into breeding plumage was accentuated once again.

### Body mass

Differences in mean body masses of Knots captured on Panaquatira Beach at different seasons were statistically significant ( $F_{6,53} = 2.275, P < 0.05$ ). On the basis of McNeil & Cadieux's (1972) formula for estimating flight range, and using Antas & Nascimento's (1996) modified value for flight velocity of 60 kph, the mean body mass at the end of April and early May ( $\bar{x} = 135$  g, range = 107-162 g,  $n=23$ ) was below the expected departure mass required to reach eastern North America.

### Feeding areas

At the beginning of the ebb tide, when the intertidal zone is uncovered, flocks of Red Knots were observed moving from their roosting areas on Curupu Island to the feeding areas on the sandy mud in Curupu Bay. Up to 600 Knots were seen foraging in this sector, associated with a few Short-billed Dowitchers. The sediment samples revealed the almost exclusive presence of the bivalve mollusc *Anomalocardia brasiliiana* ( $2.5/m^2$ ;  $n = 38$ ). Despite the variation observed in the size of *A. brasiliiana* (1.8-34.0 mm), only individuals between 1.9-2.0 mm and 5.0-7.0 mm ( $n = 20$ ) were found in the Red Knot stomach contents.

Small groups of 10 to 50 Red Knots were observed foraging along a stretch of 2 km at certain points along the inner margins of Curupu Bay. The presence at these sites of the mollusc *Mytella falcata* is clearly indicated by the fact that local fishermen were observed collecting the species for consumption.

## Discussion

### Occurrence and migration

The available data indicate that the current wintering population of Red Knots in sector 59 of Morrison & Ross (1989) may reach 2,000 individuals, somewhat less than the 3,000 individuals counted during their aerial survey of January 1986. Concentrations of 5,000 individuals, tentatively identified as Red Knots, in Cabelo da Velha Bay on the west coast of Maranhão state (sector 51, Morrison & Ross 1989) emphasize the importance of the north-central coast of Brazil as a wintering area. The records 7,000-8,000 Knots on the north-central coast of Brazil represents around 10% of the South American counts, which held 76,400 (Morrison & Ross 1989).

There is a record of the occurrence on the western coast of Maranhão, on 18 May 1987, of a Red Knot ringed at Lagoa do Peixe in southern Brazil (Morrison & Harrington 1992). At Maiaú Island, the western coast of Maranhão State, we observed on 30 April 1997, during northward migration, one bird with an orange flag which had been marked in Argentina. These data indicate that populations which winter in southern South America use the north-central coast of Brazil as an area for refuelling and moulting prior to making for the next known stopping point on Delaware Bay, eastern United States. One bird seen at Panaquatira Beach on 12 May 1997, had a green flag on the left tibia indicating that it had been ringed in U.S.A.

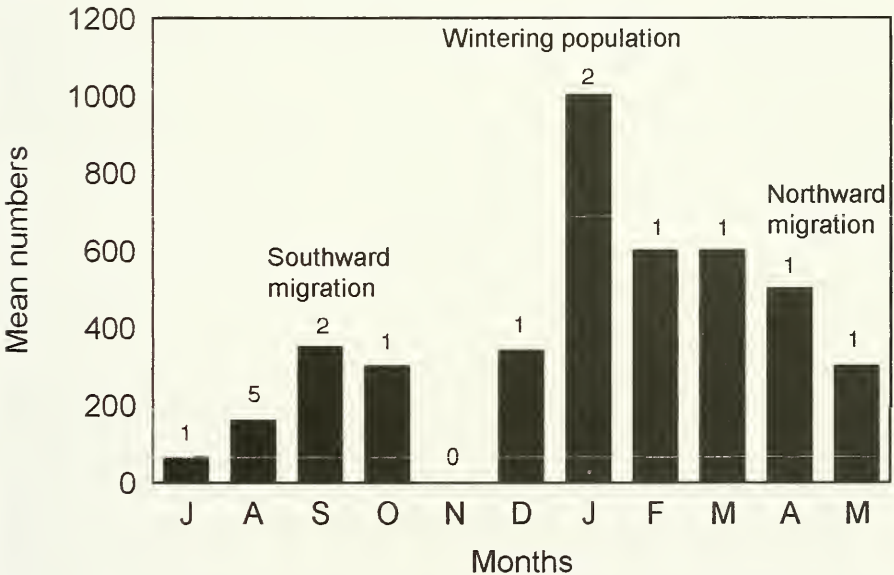


Fig. 2. Seasonal variation in the numbers of Red Knots on Panaquatira Beach and Curupu Island, Maranhão, Brazil, from July 1996 to May 1997. The numbers at the top of the columns show the number of counts on which each datum is based.



According to Morrison & Harrington (1992), during northward migration at the Lagoa do Peixe, predicted flight ranges are more than adequate for the birds to reach north-central Brazil (3,300 km) but not adequate for a direct flight to the United States (8,700 km). Red Knots from southern South America probably encounter the wintering individuals on the north-central coast of Brazil during their spring migration, which makes the separation of these populations somewhat difficult, given that both are found in their breeding plumage.

The census data indicate a small peak in numbers during the autumn, which is due to the arrival of wintering individuals on the north-central coast of Brazil, in addition to the transit of part of the population of Red Knots that winters in southern South America. At Panaquatira Beach we observed in September 1996 and August and September 1999 three Knots with orange flags indicating that they had been ringed in Argentina.

### Moult

According to Morrison & Harrington (1992) body moult into breeding plumage starts on the wintering ground. In March, the majority of wintering Red Knots at Panaquatira Beach still bore winter plumage, and the reddish breast characteristic of the breeding plumage was seen in only three individuals. Of the 18 birds captured there in early May 1997, a third were still actively body moulting into breeding plumage whereas the remainder had completed moult, with breeding plumage characteristics between 70-90% (Wilson *et al.* 1998, suggest that some of these birds were probably second year). Thus the pattern observed at Panaquatira Beach is quite different from that recorded at Lagoa do Peixe in southern Brazil, where the full breeding plumage was attained during the first two weeks of April for most of the population (Antas & Nascimento 1996). These differences are probably related with the distances to be travelled by the birds from different wintering areas.

### Body mass

The overall journey of 5,000 km between the north-central coast of Brazil and the next known stop in Delaware Bay would take some 3 days of flying at a speed of 60 km/h (Antas & Nascimento 1996: table 2). Forty-five Red Knots, caught by CEMAVE-IBAMA on Maiaú Island, had an average mass of 160 g (range 120-210 g). Masses around 200g are similar to records of departure mass, from other stopover areas where birds initiate long flights (Wilson & Morrison 1992, Davidson & Wilson 1992, Piersma *et al.* 1992) and are more than sufficient to fly non-stop over the Atlantic Ocean to reach Delaware Bay (on the basis of McNeil & Cadieux's 1972 formula). Although the mean mass of the birds captured in mid April and early May 1997 on Panaquatira Beach was below an expected departure mass of around 200 g, the peak number for Red Knots in Delaware Bay is between 26-30 May (Clark *et al.* 1993). Thus it is possible that most birds remain in the area for at least two more weeks to build up adequate fat reserves. We suggest that probably at least some of the birds

banded in Panaquaira Beach were migrating this distance because one of the seven knots banded at Salinas Beach (00°30' S; 47°20' W – north-central coast of Brazil), Pará State, on 12 April 1997 was recaptured in Delaware Bay at the end of May (A. J. Baker, pers. comm.). When initially captured in Salinas Beach, these knots apparently did not have sufficient fat reserves ( $\bar{x}$  = 105.8 g, range 90-115 g,  $n$  = 7) to fly 5,000 km. These masses are similar to those recorded in Panaquatira Beach at the same date (12 April 1997). Thus, the birds probably remained on the area long enough to accumulate sufficient fat reserves. There are some records of Knots putting on mass at 2 g to 3 g per day, and exceptionally 8 g per day (see Evans 1992). At 3 g per day a 115 g Knot caught on 12 April would be 205 g on 12 May. The heaviest Knot caught in Panaquatira Beach was 162 g on 5 May. At 3 g per day this would have reached 205 g by 20 May. Alternatively, some birds may leave the north-central coast of Brazil with departure mass less than 200 g.

A comparison of the spring census data from Maranhão with those collected by Spaans (1978) in Surinam suggests that Red Knots may use a wide area of the northern coast of South America, migrating north from a number of different points (Rodrigues, unpublished data).

### Threats to feeding sites

Roosting areas in Curupu Island are still relatively well protected and no obvious threat was identified during the present study. However, in the feeding areas, local fishermen collect large quantities of the molluscs *A. brasiliiana* and *M. falcata*, both for their own consumption and for sale in local markets (Mendes & Branco 1981). Preliminary data indicate that *A. brasiliiana* is one of the principal components of the diet of Red Knots on this sector of the coast. While the shell length of the molluscs collected by local fishermen (24-35 mm,  $n$  = 30) is larger than those taken by Red Knots (1.9-7.0 mm,  $n$  = 20), the principal threat is the over-exploitation of the adult molluscs, which would lead to a depletion of food stocks for the birds in this area. On Panaquatira Beach, the most frequent disturbance is the movement of people and vehicles, which is particularly intense during weekends, resulting in the displacement of the birds.

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## The first record of a Short-tailed Shearwater *Puffinus tenuirostris* for the Mascarene Islands

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The Short-tailed Shearwater *Puffinus tenuirostris* breeds on mainland Australia and the Tasmanian Islands. Most migrate during the non-breeding season to the north Pacific, but there is evidence of some appearing in the northern Indian Ocean between Oman and the Malay Peninsula, possibly displaced by storms (Frith 1978, Colston 1980, Marchant & Higgins 1990). We report here the first record of the species for the Mascarene Islands, south-west Indian Ocean. The bird was found by local people alive on the beach at Riviere Coco, Rodrigues on 5 June 1974. It died shortly afterwards and its remains were passed to ASC on his next visit to the island on 12 July. They were subsequently deposited in The Natural History Museum, Tring, where they are now preserved in the bird skin collection (BMNH reg. no. 1999.30.1.)

Initial identification of the specimen as *P. tenuirostris* has now been confirmed by comparison with skins of this and related species. In particular it is clearly distinguishable from the Sooty Shearwater *Puffinus griseus*, the most similar species, in having a shorter, stubbier bill and a pale grey underwing. The following measurements (mm) taken from the carcass are also consistent with other *P. tenuirostris* skins: wing 265, tarsus 51, bill 32, middle toe and claw 62. The only other evidence of the occurrence of the species in the south-west Indian Ocean appears to be a recent sight record off the south east coast of South Africa, reported without supporting details by Enticott & Tipling (1997).